~~U.S. NUCLEAR REGULATORY COMMISSION~~

~~STANDARD REVIEW PLAN~~

~~OFFICE OF NUCLEAR REACTOR REGULATION~~

2.4.4 POTENTIAL DAM FAILURES

REVIEW RESPONSIBILITIES

Primary - ~~Hydrologic & Geotechnical Engineering Branch (HGEB)~~
Mechanical and Civil Engineering Branch (EMEB)

Secondary - None

I. AREAS OF REVIEW

In this section of the ~~safety analysis report (SAR)~~ site safety assessment for an early site permit application, the hydrogeologic design basis is developed to ~~assure~~ ensure consideration ~~in plant design~~ of any potential hazard to the safety-related facilities of a nuclear power plant or plants of specified type that might be constructed on the proposed site due to the failure of upstream and downstream water control structures. The areas of review include consideration of flood waves (bores) from severe breaching of upstream dams and the potential loss of water supply due to failure of a downstream dam, domino-type failures of dams, landslides, and effects of sediment deposition and erosion.

When data are provided to show that seismic events will not cause failures of upstream dams that could produce the governing flood at a nuclear power plant or plants of specified type that might

be constructed on the proposed site ~~the plant~~, this section may contain additional data and other information to support a contention that the dams are equivalent to seismic Category I structures and will survive a local equivalent of the safe shutdown earthquake (SSE) or will survive the operating basis earthquake (OBE). In such cases, the ~~Geotechnical Engineering Section (GES) of HGEB, the Geosciences Branch (GB), and Structural Engineering Branch (SEB), as necessary,~~ EMEB will evaluate the data necessary to justify such a classification. ~~GES, GB, and SEB~~EMEB review procedures are outlined in the appropriate geosciences and structural ~~SRP~~ Standard Review Plan (SRP) sections. The balance of this SRP section applies to the hydrologic analyses of dam failures or breaches.

Where analyses are provided in support of either a conclusion that a probable maximum flood (PMF) should be the design basis flood for a stream, or that a postulated or arbitrarily assumed dam failure flood is the design basis flood for a stream, the areas of review consist of the following:

1. Conservatism of modes of assumed dam failure and deposition of debris downstream.

2. Consideration of flood control reservoirs at full pool level.

3. Conservatism of coincident flow rates and levels, depending on whether failure is postulated with an equivalent SSE coincident with a 25-year flood or an OBE coincident with a standard project flood (SPF). An SPF is considered to be about forty percent of a PMF.

4. Flood wave attenuation to downstream dams or to the site, whichever would be encountered first.

5. Potential for multiple dam failures; flood wave effects and potential for failure of downstream dams.

6. Hydraulic failure as a result of overtopping for any reason.

7. Dynamic effects of possible bores on exposed ~~plant~~ facilities of a nuclear power plant or plants of specified type that might be constructed on the proposed site.

8. Conservative flow conditions for downstream dam failures that can influence safety-related water supplies.

9. Applicability and conservatism of models used to predict the effects of dam failure floods including breach shape and rate of failure.

II. ACCEPTANCE CRITERIA

Acceptance criteria for this SRP section are based on meeting the requirements of the following regulations:

~~1. General Design Criterion 2 (GDC 2) as it relates to structures, systems, and components important to safety being designed to withstand floods.~~

2. 10 CFR Parts 52 and 100 as ~~it relates~~ they relate to evaluating hydrologic features of the site.

3. 10 CFR ~~Part~~ 100.23~~, Appendix A~~ as it relates to establishing the design basis flood due to seismic dam failure.

Section 52.17(a) of 10 CFR Part 52 and Section 100.20(c) of 10 CFR Part 100 require that the site's physical characteristics (including seismology, meteorology, geology, and hydrology) be taken into account when determining its acceptability for a nuclear power reactor.

10 CFR Parts 52 and 100 are applicable to safety assessment Section 2.4.4 because it addresses the physical characteristics, including hydrology, considered by the Commission when determining the acceptability of a site for a power reactor. To satisfy the hydrologic requirements of 10 CFR Parts 52 and 100, the applicant's safety assessment must contain a description of the hydrologic characteristics of the region and an analysis of potential dam failures. The description must be sufficient to assess the acceptability of the site and the potential for those characteristics to influence the design of structures, systems, and components important to safety. Meeting this requirement provides a level of assurance that structures, systems, and components important to safety could be designed to withstand the effects of high water levels resulting from failure of upstream

dams, as well as those of low water levels resulting from failure of a downstream dam.

10 CFR 100.23 requires consideration of geologic and seismic factors in determination of site suitability. Section 100.23(c) requires an investigation to obtain geologic and seismic data for evaluating seismically induced floods, including failure of an upstream dam during an earthquake.

10 CFR 100.23 is applicable to SRP Section 2.4.4 because it requires investigation of seismically induced floods or low water levels that guide the Commission in its consideration of the suitability of proposed sites for nuclear power plants. More detailed guidance on the investigation of seismically induced floods is provided Regulatory Guide 1.70, including results for seismically induced dam failures and antecedent flood flows coincident with the flood peak.

Meeting this requirement provides a level of assurance that structures, systems, and components important to safety could be designed to withstand the effects of seismically induced failure of upstream or downstream dams.

Note: Though not required at the early site permit stage, the applicant for a combined license (COL) will need to demonstrate compliance with General Design Criterion 2 as it relates to structures, systems, and components important to safety being designed to withstand floods.

To meet the requirements of ~~GDC 2,~~ 10 CFR Parts 52 and 100, and 10 CFR ~~Part~~ 100.23~~, Appendix A~~, as they relate to dam failures, the following specific criteria are used:

The staff will review the applicant's analyses and independently assess the coincident river flows at the site and at the dams being analyzed. ~~ANSI N170~~ ANSI/ANS-2.8-1992 provides guidance on acceptable river flow conditions to be assumed coincident with the dam failure event. The applicant's estimates (which may include landslide-induced failures) of the flood discharge resulting from the coincident events should be no more than 5% less conservative than the staff's estimates to be acceptable. If

the applicant's estimates differ by more than 5%, the applicant should fully document and justify its estimates or accept the staff's estimates ~~and redesign applicable flood protection~~.

For ~~SAR~~**safety assessment** Section 2.4.4.1 (Dam Failure Permutations): The location of dams and potentially "likely" or severe modes of failure must be identified. **Dams or embankments for the purpose of impounding water for a nuclear power plant or plants that might be constructed on the proposed site must also be identified.** The potential for multiple, seismically induced dam failures and the domino failure of a series of dams must be discussed. Approved models of the Corps of Engineers and the Tennessee Valley Authority are used to predict the downstream water levels resulting from a dam breach (Refs. 7, 11, 16, 17 and 18). First-time use of other models will require complete model description and documentation. Acceptance of the model (and subsequent analyses) is based on the staff review of model theory, available verification, and application. Where other than instantaneous failure is assumed, the conservatism of the rate of failure and shape of the breach should be well documented. A determination of the peak flow rate and water level at the site for the worst possible combination of dam failures and a summary analysis (that substantiates the condition as the critical permutation) must be presented, along with a description (and the bases) of all coefficients and methods used. Also, the effects of other concurrent events on plant safety, such as blockage of the river and water-borne missiles, must be considered.

For ~~SAR~~**safety assessment** Sections 2.4.4.2 (Unsteady Flow Analysis of Potential Dam Failures) and 2.4.4.3 (Water Level at Plant Site): The effects of coincident and antecedent flood flows (or low flows for downstream structures) on initial pool levels must be considered. Use of the methods given in References 4 or 6 is acceptable for determination of initial pool levels. Depending upon estimated failure modes and the elevation difference between plant grade and normal river levels, it may be acceptable to use conservative simplified procedures to estimate flood levels at the site. Where calculated flood levels using simplified methods are at or above plant grade and using assumptions which cannot be demonstrated as conservative, it will be necessary to use unsteady flow methods to develop flood levels at the site. References 11 and 12 are acceptable methods; however, other programs would be acceptable with proper documentation and justification. Computations, coefficients, and methods used to

establish the water level at the site for the most critical dam failures must be summarized. Coincident wind-generated wave activity should be considered in a manner similar to that discussed in SRP Section 2.4.3.

Appropriate sections of the guides described below are used by the staff to determine the acceptability of the applicant's data and analyses. Regulatory Guide 1.59, which incorporates ANSI N170 (subsequently revised to ANSI/ANS-2.8-1992), provides guidance for estimating the design basis for flooding considering the worst single phenomenon and combination of less severe phenomena. Regulatory Guide 1.29 identifies the safety-related structures, systems, and components, and Regulatory Guide 1.102 describes acceptable flood protection to prevent ~~the~~ safety-related facilities from being adversely affected.

III. REVIEW PROCEDURES

The conservatism of the applicant's estimates of flood potential and low water levels from structure failures is judged against the criteria indicated in subsection II above. An analysis is performed using simplified, conservative procedures (such an instantaneous failure, coincident SPF flows, minimal flood wave attenuation, and extrapolated site discharge-rating curves). Techniques for such analyses are identified in standard hydraulic design references and text books, such as those listed in the reference section. If no potential flood problem exists, the staff safety evaluation report (SER) input is written accordingly. If the simplified analysis indicates a potential flooding problem, the analysis is repeated using a more refined technique which may include time rate of failure and hydrometeorologically compatible storm centering. Detailed failure models, such as those of the Corps of Engineers and the Tennessee Valley Authority, are utilized to identify the outflows from various failure modes. Models of the Corps of Engineers or the Tennessee Valley Authority are used to identify the outflow characteristics and resultant water level at the site (Refs. 7, 11, 12, 16, 17, and 18). The staff will develop a position based on the analyses performed; resolve, if possible, differences between the applicant's and staff's estimates; and write the SER input accordingly.

The above reviews are performed only when applicable to the site or site region. Some items of review may be done on a generic basis.

IV. EVALUATION FINDINGS

For ~~construction permit (CP)~~ **early site permit** reviews, the findings will summarize the applicant and staff evaluations in compliance with ~~GDC 2,~~ 10 CFR Part**s 52 and** 100; and 10 CFR ~~Part~~ 100**.23**~~,~~ ~~Appendix A~~, of the design basis maximum and minimum water levels caused by potential dam failures. If the applicant's estimates are within acceptable margins (described in subsection II), staff concurrence in the applicant's estimates will be stated. If the applicant's estimates are not within acceptable margins, and if ~~the plant~~ **a nuclear power plant or plants of specified type that might be constructed on the proposed site** may be adversely affected, a position requiring use of the staff bases will be stated. If no dam failure review was undertaken at the **early site permit** ~~construction permit~~ stage (of the scope described), this fact will be indicated. **Evaluation of a dam constructed after issuance of an early site permit would need to be performed at the COL stage.**

~~For operating license (OL) reviews of cases for which detailed potential dam failure analyses were made during the CP review, the CP-stage conclusions will be referenced. In addition, any further review done to reaffirm the maximum or minimum water levels based on any new information will be described and the results and conclusions stated.~~

Sample statements for **early site permit** reviews follow:

> ~~The staff concludes that the plant design flood elevation, at plant grade of 50 feet MSL, is acceptable and meets the requirements of General Design Criterion 2, 10 CFR Part 100, and 10 CFR Part 100, Appendix A, with respect to potential hazards due to dam failure floods. This conclusion is based on the following evaluation.~~
>
> **As set forth above, the** ~~The~~ distance (more than ~~300 miles~~ **480 km** (300 mi)) to upstream reservoirs of appreciable size is such that the staff assessment leads to the conclusion that their arbitrarily assumed failure, under postulated combinations of floods and earthquakes of the severity

discussed in Regulatory Guide 1.59, would not constitute a threat to ~~the plant~~ a nuclear power plant of specified type that might be constructed on the proposed site.

Dam failure-caused "worst case" floods were evaluated by the applicant based upon failures with consideration of only the location and sizes of upstream impoundments, and not on inherent capability of such structures to resist earthquakes, volcanic activity, and severe landslide-induced floods. The most severe flood of this kind was estimated based upon an assumed catastrophic failure of Dam A some ~~420 miles~~ 680 km (420 mi) upstream. The peak flow at the site from such a flood was estimated to be ~~3,000,000 cfs~~ 85,000 m^3/s (3,000,000 cfs). This flow is estimated to occur about 2 days after the dam failure and reach elevation ~~41 feet~~ 12 m (41 ft) MSL, ~~9 feet~~ 3 m (9 ft) below plant grade.

A volcanically induced flood was assumed to cause a domino-type failure of the three dams on the tributary B River from a volcanic eruption of Mt. D. The evaluation indicated such an event could cause the second most severe artificial flood that would reach the site. This event was estimated to produce a peak flow at the site of ~~2,800,000 cfs~~ 80.000 m^3/s (2,800,000 cfs) and a water level of ~~39 feet~~ 12 km (39 ft) MSL, ~~11 feet~~ 3 m (11 ft) below plant grade.

Therefore, the staff concludes that the plant design flood elevation, at plant grade of 15 m (50 ft) above mean sea level (MSL), is acceptable and meets the requirements of 10 CFR Parts 52 and 100, and 10 CFR 100.23 with respect to potential hazards due to dam failure floods.

The findings will address the envelope of site-related hydrologic parameters. These parameters should be representative of the most severe hydrologic characteristics likely to occur as a result of dam failure.

V. IMPLEMENTATION

The following is intended to provide guidance to applicants and licensees regarding the NRC staff's plans for using this SRP section.

This SRP section will be used by the staff when performing safety evaluations of early site permit applications submitted by applicants pursuant to 10 CFR Part 52. Except in those cases in which the applicant proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, the method described herein will be used by the staff in its evaluation of conformance with Commission regulations.

Implementation schedules for conformance to parts of the method discussed herein are contained in the referenced regulatory guides.

VI. REFERENCES

1. 10 CFR Part 50, Appendix A, General Design Criterion 2, "Design Bases for Protection Against Natural Phenomena."

2. 10 CFR Part 100, "Reactor Site Criteria."

~~3. 10 CFR Part 100, Appendix A, "Seismic and Geologic Siting Criteria for Nuclear Power Plants."~~

4. "Flood Hydrograph Package," HEC-1, Corps of Engineers Hydrologic Engineering Center, Davis, California, ~~October 1970~~ June 1998

5. "Water Surface Profiles," HEC-2, Corps of Engineers Hydrologic Engineering Center, Davis, California, ~~February 1972~~ February 1991

6. "~~Reservoir System Operation for Flood Control~~ Simulation of Flood Control and Conservation Systems," HEC-5, Corps of Engineers Hydrologic Engineering Center, Davis, California, ~~May 1973~~ October 1998.

7. "Routing of Floods Through River Channels," EM 1110-2-1408, Corps of Engineers, March 1960.

8. Hunter Rouse, ed., "Engineering Hydraulics," John Wiley & Sons, Inc., New York (1950).

9. Ven Te Chow, "Open-Channel Hydraulics," McGraw-Hill Book Co., New York (1959)

10. Ven Te Chow, ed., "Handbook of Applied Hydrology," McGraw-Hill Book Co., New York (1964).

11. J. M. Garrison, J. P. Granju, and J. T. Price, "Unsteady Flow Simulation in Rivers and Reservoirs," Jour. Hydraulics Division, Proc. Am. Soc. of Civil Engineers, Vol. 95, No. HY5, pp. 1559-1576 (1969).

12. "Gradually Varied Unsteady Flow Profiles," 723-62-L2450, Corps of Engineers Hydrologic Engineering Center, Davis, California, March 1969.

13. R. A. Baltzer and C. Lai, "Computer Simulation of Unsteady Flows in Waterways," Hydraulics Division, Proc. Am. Soc. of Civil Engineers, Vol. 94, No. HY4, pp. 1083-1117 (1968).

14. J. J. Stoker, "Numerical Solution of Flood Prediction and River Regulation Problems," Reports I and II, New York Univ. (1953-54).

15. V. L. Streeter and E. B. Wylie, "Hydraulic Transients," McGraw Hill Book Co., New York, pp. 239-259 (1967).

16. W. A. Thomas, "A Method for Analyzing Effects of Dam Failures in Design Studies," Corps of Engineers Hydrologic Engineering Center, Davis California (for presentation at the ASCE Hydraulics Division Specialty Conference, Cornell University, August 1972).

17. "Flow Through a Breached Dam," Military Hydrology Bulletin No. 9, Corps of Engineers (1957).

18. "Floods Resulting From Suddenly Breached Dams, Conditions of High Resistance," Misc. Paper No. 2-374, Report 2, Corps of Engineers (1961).

19. Bureau of Reclamation, "Flood Routing," Chapter 6/0 in "Flood Hydrology,"Part 6 in “Water Studies," Volume IV, U.S. Department of the Interior (1947).

20. Regulatory Guide 1.70, "Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants."

21. Regulatory Guide 1.59, "Flood Design Basis for Nuclear Power Plants."

22. ~~ANSI N170, "Standards for~~ ANSI/ANS-2.8-1992, "Determining Design Basis Flooding at Power Reactor Sites."

23. Regulatory Guide 1.29, "Seismic Design Classification."

24. Regulatory Guide 1.102, "Flood Protection for Nuclear Power Plants."

25. 10 CFR Part 52. "Early Site Permits; Standard Design Certifications; and Combined Licenses for Nuclear Power Plants."

26. "Inflow Design Floods for Dams and Reservoirs." Regulation No. 1110-8-2 (FR), U.S. Army Corps of Engineers Engineer , 1991.

27. National Research Council (NRC). Safety of Dams : Flood and Earthquake Criteria, National Academy Press, Washington, D.C., 1985.

28. Dewey, R., and D. Gillette, 1993. "Prediction of Embankment Dam Breaching for Hazard Assessment." Proc. Specialty Conference on Geotechnical Practice in Dam Rehabilitation,ASCE, 25-28 April 1993, Raleigh, North Carolina.

29. Froehlich, D. 1987. "Embankment-Dam Breach Parameters." Proc. 1987 National Conference on Hydraulic Engineering, ASCE, 3-7 August 1987, Williamsburg, Virginia. pp. 570-575.

30. Froehlich, D. 1995. "Embankment Dam Breach Parameters Revisited." Proc. Conference on Water Resources Engineering, ASCE, 14-18 August 1995, San Antonio, Texas.

31. MacDonald, T., and J. Langridge-Monopolis, 1984. "Breaching Characteristics of Dam Failures." J. Hydraul. Eng. 110(5):567-586.

32. Von Thun, J. L., and D. Gillette, 1990. "Guidance on Breach Parameters." U.S. Bureau of Reclamation, Denver, CO, 13 March 1990 (unpublished internal document). 17 pp.

33. U.S. Bureau of Reclamation. Training Aids for Dam Safety. Module: Evaluation of Hydrologic Adequacy, Technical Service Center, Denver, CO, 1990.

34. Committee on Safety Criteria for Dams. Safety of Dams - Flood and Earthquake Criteria. Prepared under the Auspices of Water Science and Technology Board. Commission on Engineering and Technical Systems. National Research Council, Washington, D.C., National Academy Press, 374 pp., 1985.

35. Cecilio, C. B. and A. G. Strassburger. Downstream Hydrograph from Dam Failure. Engineering Foundation Conference on Evaluation of Dam Safety, 1976.

36. Gandlach, D. L. and W. A. Thomas. "Guidelines for Calculating and Routing a Dam-Break Flood." Research Note No. 5. U.S. Army Corps of Engineers, Hydrologic Engineering Center, 1977.

37. Fread, D. L.. DAMBRK - The NWS Dam-Break Flood Forecasting Model. National Weather Service, Silver Spring, Maryland, 1988 Version.

38. Westmore, Jonathan N. and Danny L. Fread. The NWS Simplified Dam-Break Flood Forecasting Model, National Weather Service, Silver Spring, Maryland, 1981.

39. U.S. Bureau of Reclamation. Training Aids for Dam Safety. Module: Evaluation of Hydrologic Adequacy, Technical Service Center, Denver, CO, 1990.

40. American Society of Civil Engineers. "Evaluation Procedures for Hydrologic Safety of Dams." Report by the Task Committee on Spillway Design Flood Selection. Committee on Surface Water Hydrology, Hydraulics Division, New York, New York, 1988.

Figure 2.4.4-1

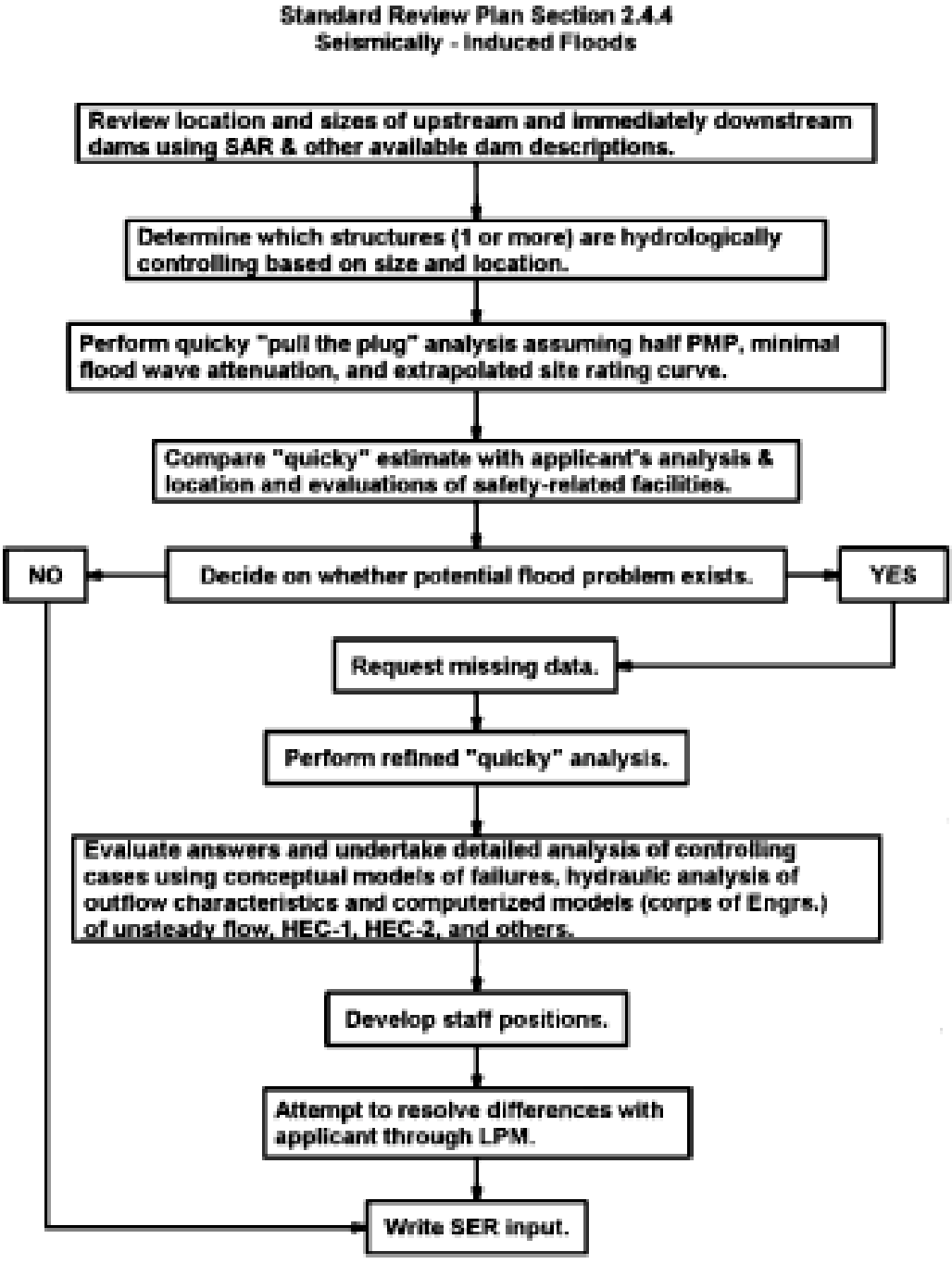

FIGURE DELETED